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FACSIMILE TRANSMISSION STANDARDS

by

Andrew Mudry and Brad Poulin

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE 93-18

Canada

DTIC QUALITY INSPECTED 1

October 1993
Ottawa

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Andrew Mudry and Brad Poulin
Communications Electronic Warfare Section
Electronic Warfare Division

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ABSTRACT

Modern tactical communications systems are becoming increasingly compatible with existing civilian systems. This compatibility allows the military to take advantage of the equipment available commercially and spare the expense of developing costly customized systems. It also increases the interoperability of various communications systems employed by allies involved in multinational operations. Finally, the compatibility allows the military to augment its telecommunications assets with existing commercial equipment and networks during times of conflict. One civilian communication standard that has recently been adopted by the military for tactical communications is that of facsimile. Facsimile is now commonly used on the battlefield for the transmission of tactical maps and situation reports.

This technical note examines the requirements for facsimile transmission. An overview of the various facsimile standards are given, followed by a detailed description of the most commonly used standard; CCITT Group III. The Group III specifications are a composite of various CCITT modulation and encoding standards. These consist of V.21, V.27*ter*, and V.29 modulations, as well as T.4 image encoding standards, and T.30 signalling specifications. Each of these standards is described in the context of facsimile transmissions. A complete description of the handshaking which occurs between the facsimile transmitter and receiver is given.

RÈSUME

Les systèmes modernes de communications tactiques sont de plus en plus compatibles avec les systèmes civils. Cette compatibilité permet à la Défense de profiter du matériel actuellement disponible sur le marché, ce qui lui évite les dépenses liées à la mise au point de systèmes faits sur mesure. De plus, cela augmente l'intéropérabilité des divers systèmes de communications utilisés par des alliés participant à des opérations multinationales. Enfin, cette compatibilité permet à la Défense d'accroître, en temps de guerre, l'ensemble de ses équipements de télécommunications à l'aide d'équipements et de réseaux commerciaux existants. Le télécopieur est l'une des normes de communications civiles qui a été adoptée par la Défense pour les communications tactiques. A l'heure actuelle, les télécopieurs sont couramment utilisés sur le champ de bataille pour transmettre les cartes tactiques et les compte rendu de situation.

La présente note technique expose les éléments necéssaires à la transmission de télécopies. Nous présentons d'abord une vue d'ensemble des diverses normes de télécopie, puis nous procédons à une description détaillée de la norme la plus communément utilisée, CCITT Groupe III. Les caractéristiques techniques du Groupe III proviennent de diverses normes de modulation et de codage CCITT notamment: les modulations V.21, V.27ter et V.29; des normes de codage d'images T.4 ainsi que des caractéristiques techniques de signalisation T.30. Chacune de ces normes sont décrites dans le cadre des transmissions par télécopieur. Nous décrivons également, en détail, la prise de contact entre l'appareil transmetteur et l'appareil récepteur de télécopie.

EXECUTIVE SUMMARY

Modern tactical communications systems are becoming increasingly compatible with existing civilian systems. This compatibility allows the military to take advantage of the equipment available commercially and spare the expense of developing costly customized systems. It also increases the interoperability of various communications systems employed by allies involved in multinational operations. Finally, the compatibility allows the military to augment its telecommunications assets with existing commercial equipment and networks during times of conflict. One civilian communication standard that has recently been adopted by the military for tactical communications is that of facsimile.

Radio facsimile has been employed by the military in the past, but due to the size of the equipment and the poor reliability its use as a mode of battlefield communications was very limited. It was used mainly for the transmission of meteorological maps. Today however, the demand by the civilian business community has improved the cost, size, and reliability of facsimile transceivers to the point where it is now a viable form of tactical communications. Facsimile is now commonly used on the battlefield for the transmission of tactical maps and situation reports. It could also be used for the transmission of computer generated images over a tactical radio link.

This technical note examines the requirements for facsimile transmission. An overview of the various facsimile standards are given, followed by a detailed description of the most commonly used standard; CCITT Group III. The Group III specifications are a composite of various CCITT modulation and encoding standards. These consist of V.21, V.27*ter*, and V.29 modulations, as well as T.4 image encoding standards, and T.30 signalling specifications. Each of these standards is described in the context of facsimile transmissions. A complete description of the handshaking which occurs between the facsimile transmitter and receiver is given.

In the military environment, the users are generally mobile. The baseband facsimile signal is generally modulated onto a Radio Frequency (RF) carrier and carried over a wireless radio link. Only the baseband facsimile signals are discussed in this technical note. Techniques for modulating this information onto an RF carrier are not discussed.

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1.0 INTRODUCTION

Modern tactical communications systems are becoming increasingly compatible with existing civilian communications systems. This compatibility allows the military to take advantage of the equipment available commercially thereby sparing the expense of developing costly customized systems. It also increases the interoperability of various communications systems employed by allies involved in multinational operations. Finally, the compatibility allows the military to augment its telecommunications assets with existing commercial equipment and networks during times of conflict. In small and medium intensity engagements it can reasonably be assumed that many of these commercial networks will remain intact. As an example commercial terrestrial microwave links located in Saudi Arabia, as well as satellite links, were leased by the U.S. military during operation Desert Storm [1]. Current U.S. Army doctrine calls for an increase in the compatibility of military assets with commercial equipment. It is therefore reasonable to assume that the standards employed in future military communications systems will closely parallel the civilian standards.

One civilian communication standard that has recently been adopted by the military for tactical communications is that of facsimile. Facsimile has been employed by the military in the past, but due to the size of the equipment and the poor reliability its use as a mode of battlefield communications was very limited. It was used mainly for the transmission of meteorological maps. Today however, the demand by the civilian business community has improved cost, size, and reliability of facsimile transceivers to the point where it is now a viable form of tactical communications. Facsimile is now employed extensively on the battlefield for the transmission of tactical maps, and situation reports. The new Mobile Subscriber Equipment (MSE) which has recently been fielded by the United States Army provides facsimile capability for both fixed and mobile users at echelon corps and below [1]. The main distinction in the military application of facsimile is that users are generally mobile. At some point between the transmitting and receiving fax, the signal is carried on a wireless radio link.

This technical note examines the standards used for tactical facsimile transmission. An overview of the various facsimile standards are given, followed by a detailed description of the most commonly used standard. Modulation formats and encoding schemes for the image are discussed in detail, as well as the protocol communications which occur between transmitter and receiver at the beginning of the transmission.

2.0 OVERVIEW OF FACSIMILE TRANSMISSION

Currently, there are four standards for facsimile transmission which have been adopted by the International Telegraph and Telephone Consultive Committee (CCITT). They are Group I, Group II, Group III, and Group IV. These standards specify parameters such as scanning direction, size of scan line, number of scan lines per millimetre, scanning rate, phasing, synchronization, and modulation techniques. Over 98 percent of the facsimile machines currently in use employ the modulation and encoding techniques outlined in the Group III recommendations [2]. These will be described in detail in the following section. Group I and

II machines are now obsolete, and are rarely seen. Group IV machines have not yet gained wide acceptance, as they are intended for a four wire ISDN network, and cannot be used on a standard two wire line.

All facsimile machines contain a scanner which converts the graphics image to an electrical signal. This is done by reflecting a light from the surface of the document being scanned. Black areas of the document reflect less light than the white areas. The reflected light is detected by a photoelectric cell which produces an electrical signal proportional to the intensity of the reflected light. Normally, a tiny spot of light is generated by a lamp and a focusing lens. This is then scanned across the entire document. This technique is known as spot scanning. A second scanning technique, known as flood scanning, involves the illumination of the document with a diffuse light in the area of the scan. The reflected light is then projected through a very small aperture lens, onto the photoelectric cell [3].

Group I facsimile machines employed a spinning drum scanner with a spot scanning illumination technique. The page to be scanned was mounted on a cylinder, which was attached to a synchronous AC motor and a feeding screw. As the cylinder revolved, it was slowly moved up by the turning of the feeding screw [4]. The document was thus scanned in a helical manner with effectively 1144 scan lines for a standard A4 sized page (210 mm x 297 mm). Group II, as well as more recent machines, use a flatbed scanning technique in which the document is fed past a slot aperture, using a stepper motor, as shown in Figure 1.1 [4].

Group II facsimile used 1145 scan lines per standard page length of 297 mm. Horizontal lines of the document were scanned continuously, and the signal produced by the photoelectric cell was analog. Group III machines introduced digital scanning techniques in which the single photoelectric cell was replaced with a Charged Coupled Device (CCD) array of 1728 photosensors. Thus, each line of the document is quantized into 1728 picture elements, which may be either black or white. As will be seen in the next section, Group III specifications also allow the option of more picture elements per line. A less expensive form of digital scanning involves the use of Contact Image Sensor (CIS) scanners. In this technique, a thin electro-optical sensor tube is extended across the slot aperture. The tube is separated from the document by a thin coating of transparent material. Again, light reflected from the surface of the document forms a pattern on the tube which is detected electronically [4]. The result is a binary pattern, identical to that obtained by the CCD array, which represents the black and white picture elements on the line being scanned. Group IV machines will use digital scanning techniques similar to those of Group III machines, but will likely provide for higher resolutions.

In Group I and Group II machines, the analog electrical signal produced by the photocell had frequency components which varied from DC to lower audio frequencies. Much of the critical information was contained in sub-audio range. In order to transmit this information over a standard telephone voice grade channel, which has a transmission capability of 300 - 3400 Hz, the electrical signal from the photocell was used to amplitude or frequency modulate an audio oscillator. The modulated audio signal was then transmitted over the voice grade channel. Group I facsimile used amplitude modulation exclusively on wire line circuits, with a carrier frequency between 1300 - 1900 Hz. Frequency modulation was used on those circuits where a radio link was employed between transmitting and receiving facsimile machines. In this case, a frequency of 1500 Hz was used to represent black, and 2300 Hz was used to represent white.

Group II facsimile transmitters used a more bandwidth efficient Vestigial SideBand (VSB) modulation technique, with a carrier frequency of 2100 Hz.

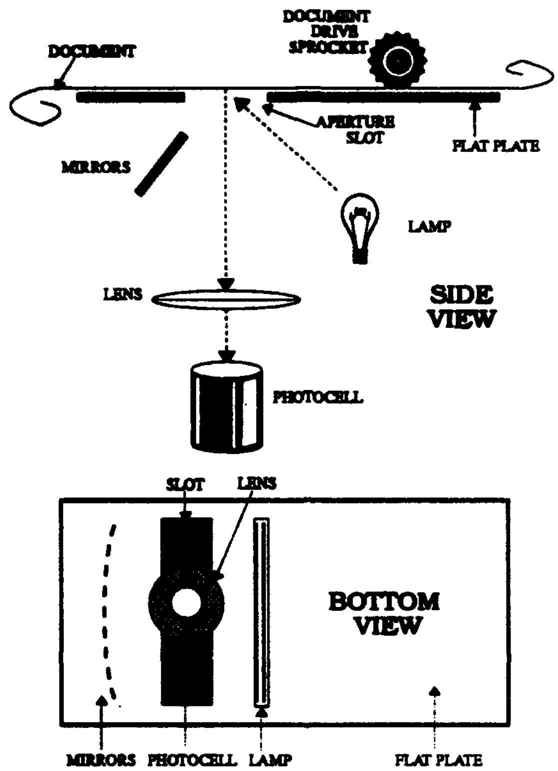

Figure 1.1: Facsimile Scanner

Due to the analog scanning techniques employed in Group I and Group II machines, the bandwidth constraints of the voice grade channel became the limiting factor in the scanning rate of the document. As the document was scanned faster, the frequency content of the photocell signal increased. This increased the bandwidth of the modulated signal. If the document was scanned too fast, the bandwidth of the modulated signal would exceed that allowed by the voice grade channel. It is for this reason that scanning speeds in Group I facsimile machines were limited to approximately 180 lines per minute. This resulted in a period of approximately 6 minutes for the transmission of a standard page of text. The bandwidth efficiency of the Group II VSB modulation allowed the scanning speed to be doubled to 360 lines per minute (approximately 3 minutes per page). Group III and IV facsimile standards allow the document to be scanned at a rapid rate and stored in memory. This separates the scanning speed from the bandwidth requirements. The voice grade channel bandwidth and quality does affect the rate at which the stored information may be transmitted, but overall there is a gain achieved since a Group III machine is capable of scanning a document in a few seconds, and can transmit a standard page of text in less than a minute [2].

On the receive side, there are four main techniques that have been used to reproduce the original document from the transmitted signal: 1) electrolytic recording, 2) electrothermal recording, 3) electropercussive recording, and 4) electrostatic recording. As in the transmitting scanner, either a drum or a flatbed carriage may be used. In each case the demodulated audio signal is used to reconstruct the baseband signal created by the photocell in the transmitting facsimile. In electrolytic recording, specially treated paper is passed between two electrodes. The first electrode is fixed and is either the drum on a drum recorder, or the backplate on a flatbed carriage. The second electrode is a moving stylus, which moves across the page at the same rate as horizontal lines are scanned in the transmitting fax. The demodulated audio signal causes an electric current to be passed through the paper as it flows between the two electrodes. The intensity of the discoloration is proportional to the current which is passed through the paper. The current is directly proportional to the demodulated audio signal, which of course provides an indication of the black and white areas on the original document. As a result, the image on the original document is duplicated at the receiver [3].

Electrothermal recording is very similar to electrolytic recording, and has been the most popular recording method used on facsimiles in the past. In this technique, specially treated paper is again placed between two electrodes. The paper is treated in such a way that the high temperature caused by arcing electric current through the paper causes a darkening of the paper. In the more recent machines employing thermal recording techniques the printhead is composed of an array of elements arranged in a line across the width of the page. The incoming signal activates selected elements and reproduces the transmitted line on the page [5].

Electropercussive recording involves the use of carbon paper placed between the stylus and a plain white sheet of paper. The stylus is made to vibrate by an amount proportional to the level of the demodulated audio signal. This causes a carbon impression to be made on the paper which reproduces the transmitted line [3].

The final recording technique used in standard facsimile machines is electrostatic recording. It is expected to become the most popular technique in future machines, since it allows the incoming document to be reproduced on a standard sheet of paper. Treated paper is not required. This process is similar to that used in office photocopiers, and laser printers. A modulated laser beam is used to scan a photosensitive drum. The drum is scanned in a helical pattern similar to that described earlier for electrolytic recording. The laser is turned on for areas of the scan line which are to be black. The light charges the corresponding areas of the drum, and as the drum is rotated, an electrostatic image of the document is placed on the drum. The drum is then exposed to the toner, which is a black resin powder bound to charged iron filings. The toner is electrostatically attracted to the areas of the drum which were exposed to the laser light. The toner is then transferred to a sheet of paper, where it maintains the image that was present on the drum. Finally, the paper is passed through a heated roller which fuses the toner to the paper creating a permanent image [6].

Although it is not used in standard facsimile machines, another receiving technique that is growing in popularity is the use of a custom card resident inside of a PC. The received fax is demodulated and stored in memory on the computer. An image is then displayed on the PC screen. Software is generally available for obtaining a hard copy output using the existing print facilities. These custom cards are also capable of facsimile transmission, but do not generally

provide a scan capability. A separate scanner must be used to read the image into the computer prior to transmission, unless appropriate graphics conversion software is available.

Group I and Group II facsimile standards did not allow for the storage of information at any point between the scanner and the sheet of paper at the receiver. As a result, the image was received and reproduced at the receiver as it was being scanned at the transmitter. This meant that techniques were required to ensure that the receiver started to print at the right time, the stylus in the receive facsimile moved at the same rate as the stylus in the transmitting facsimile, and that the paper in the receiving facsimile was advanced at the proper rate. Automatically aligning the receiver stylus at the beginning of the page when scanning at the transmitter commenced was known as phasing the transmitter and receiver. This was generally achieved by the transmission of a special signal at the beginning, just prior to the start of scanning. In Group I standard transmitters, the phasing signal was an alternating series of white and black sequences modulated onto the carrier. The white portion of the signal made up 4 to 6 percent of the total scanning line length. The receiver retarded the spinning of its drum until the beginning of the page coincided with the middle of the white portion. At that point, the receiver was properly phased and recording was started. Group II transmitters used a similar technique, except that white was transmitted for 94 - 96 percent of the total line and black was transmitted for the remainder. Phasing at the receiver took place using the middle of the black area [7]. As mentioned earlier, Group III and IV standards allow for the storage of information between the transmitter. This eliminates the requirements for phasing of transmitter and receiver scanners, although it is still necessary to train the demodulators.

Once the transmitter and receiver are properly phased, it must be ensured that the two drums spin at the same rate, or that the paper is moved up in the carriage at the appropriate speed. In Group I and Group II machines, this was generally achieved using AC motors which were synchronized to the power grid or a common frequency standard. This technique however had a disadvantage in that it was difficult to send facsimiles internationally between countries having different power line frequencies. Alternatively, the receiver facsimile machine was slaved to a continuous synchronization signal sent by the transmitting facsimile. As will be seen, Group III and Group IV facsimile transmitters contain enough information in the header that neither power line frequency synchronization, nor a continuous synchronization signal is required.

The final requirement necessary for the proper reception of a transmitted facsimile is that the scan density and page width of the transmitter and receiver scanners must be compatible. In Group I and II machines, a parameter known as the Factor Of Cooperation (FOC) was specified. This constant was equal to the product of the scan density, measured in lines per inch, and the stroke length, measured in inches. The stroke length was equal to the width of the printed text or image on the page. In order for a reconstructed image to be a faithful reproduction (or reasonable facsimile) of the original, it was necessary that the two machines used the same FOC. This did not preclude the images being different sizes, it merely guaranteed that the image was reproduced with the same aspect ratio as the original. In Group I and II machines, the standard Factor Of Cooperation was 829. An equivalent parameter, the Index Of Cooperation (IOC) , was also used. The IOC was 0.318 times the FOC [3]. As will be seen, Group III and IV facsimile standards have also eliminated the requirement for a factor of cooperation specification.

3.0 GROUP III FACSIMILE SPECIFICATIONS

3.1 Overview

As mentioned in the previous section, Group III standards eliminate many of the synchronization problems which exist in Group I and Group II machines. All information necessary for the proper reconstruction of the image is transmitted with the image. No external synchronization signals are required. The digital scanning techniques employed in the Group III standards allow a standard vertical scanning resolution of 3.85 lines/mm. An optional higher resolution vertical scanning resolution of 7.7 lines/mm may also be provided [8]. In the horizontal direction, the standard specifies that a horizontal line of width 215 mm shall be quantized into 1728 Picture ELements (PELS). The standard also allows the storage of data between the transmitter and the receiver scanners. This allows the document to be rapidly scanned into memory and then transmitted at the highest speed possible for the link used. Typically, a standard page of text can be scanned into the transmitter in approximately 5 - 10 seconds and can be transmitted in less than a minute. The standard also allows handshaking between the transmitter and receiver for adaptive data rate adjustment prior to transmission, in order to compensate for a noisy channel. The transmitter will send a header to the receiver at the highest data rate it is capable of transmitting. If it fails to receive the proper confirmation from the intended receiver, it will retransmit the header at a progressively lower data rate, until the receiver confirms proper data reception. At that point, the transmitter will send the image. The storage of the image in memory also allows error correction codes to be added to the data before it is sent, allowing for a reduced error rate.

The Group III facsimile transmission is divided into the five distinct phases shown in Figure 3.1. Phase A consists of the establishment of a communications link between the transmitter and receiver. On a normal telephone link this is done when the originating station dials up the intended receiver. Once the dial tone is detected, the calling unit sends the dialled information to the central switching office. The switching office then routes the call between the originator and the intended receiver, and sends a RING signal to the intended receiver. When the intended receiver acknowledges the RING signal the link is completed. For tactical communications systems the process is similar except that at some point the two way conversation between the originator and the receiver is carried on either a full, or half duplex radio link. To aid in the automatic connection of facsimile machines during Phase A, the called facsimile always sends a called station identification (CED) signal upon answering. This consists of a 2100 Hz tone of duration 2.4 to 4.0 seconds. The purpose of the CED signal is to identify the called station as a non speech terminal. Phase B of the transmission is the pre-message procedure. During this phase, the transmitter and receiver identify and select mutually compatible parameters for the transmission of the fax image, which follows in Phase C. Phase C also consists of in message procedure composed of message synchronization, error detection and correction, and line supervision. Phase D of the transmission is the post message procedure during which multipage, confirmation, and end of message signalling takes place. Phase E is the call release, where the communications link between transmitter and receiver is broken and the links are returned to the control of the switching station for reallocation.

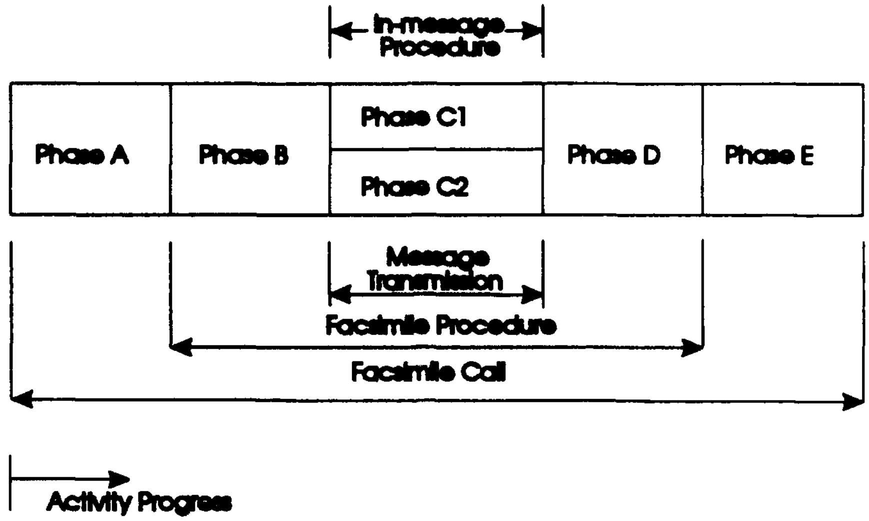

Figure 3.1: Facsimile Sequence

Figure 3.2 shows the call procedure for the case where the transmitting facsimile machine is the call originator. This is the most common situation. Those signals which are not contained in brackets are required signals. These are essential for the proper transmission and reception of the facsimile. Failure to receive a required signal after an appropriate time out generally results in termination of the call by either the transmitter or the receiver. As indicated, the Group III standards also allow for the transmission of various optional signals. The signals indicated in Table 3.2 are each transmitted in a group of one or more frames of bits. The exact structure of these frames will be discussed in Section 3.2. In cases where a group of bits contains one or more optional frames along with the required frame, the required frame will be the last group of bits transmitted.

As can be seen from Figure 3.2, the first two sequences of information are provided by the called machine. It must first identify itself as a non voice terminal using the CED tone. This is followed by a Digital Identification Signal (DIS), in which the called facsimile identifies its transmission and reception capabilities to the call originator. In addition to the DIS, two optional signals may be transmitted at this time. The Non Standard Facilities (NSF) frame is used to allow facsimile manufacturers to specify additional transmission features which are not covered in the Group III standards. These features are specific to the machine, and are generally recognized only by another machine of the same type or manufacturer. A second optional frame, which may be transmitted at this time, is the Called Subscriber Information (CSI) signal. This group of bits is used to indicate the international telephone number of the called machine.

Calling Transmitter Procedure		Called Receiver Procedure
	Phase A	
	←	1. Transmit CED
	Phase B	
3. Detect DIS	←	2. Transmit DIS, (NSF), (CSI)
4. Transmit DCS, (TSI), (NSS)	→	5. Detect DCS
		6. Select Mode
7. Transmit Phasing/Training Sequence	→	8. Phasing/Training
10. Detect CFR	←	9. Transmit CFR
	Phase C	
11. Transmit Image	→	12. Receive Image
	Phase D	
13. At end of page send one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS,PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS	→	14. Detect one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS,PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS
16. Receive MCF or RTP. If Document Transmission Is Complete, Proceed To Phase E, Otherwise Go Back To Phase B, or C	←	15. Transmit MCF or RTP
	Phase E	
17. Transmit DCN	→	18. Receive DCN
19. Disconnect		19. Disconnect

Figure 3.2: Facsimile Procedure For Calling Transmitter and Called Receiver

Upon reception of the DIS frame, the calling facsimile analyses the capabilities of the receiver and selects a transmission mode compatible with the receiver capabilities. The transmitter then responds with a Digital Command Signal (DCS), in which it specifies the modulation and data rate that will be used for the transmission of the image information. Any optional parameters to be used by the transmitter are indicated in a Non Standard facilities Setup (NSS) signal, which is sent in response to a NSF frame. Another optional signal, which may be sent by the transmitter to the receiver at this time, is the Transmitting Subscriber Information (TSI) signal. This is used by the transmitter to identify its telephone number. Upon reception of the DCS signals the receiver configures itself for the reception of a training sequence from the transmitter. This training sequence will be sent in the modulation format specified in the DCS, and allows the receiver modem to train and phase itself for proper reception. Its exact structure will be detailed in Section 3.3. Following the training sequence, the transmitter then sends a series of zeros in the same modulation format. This allows the receiver to assess the suitability of the channel for the chosen modulation, and data rate. If the zeros are received with an acceptable bit error rate, the receiver will respond with a ConFirmation to Receive (CFR) signal. If the receiver determines that the bit error rate is unacceptable, it will respond with a Failure To Train (FTT) signal. The transmitter will then select a lower data rate and issue another DCS, followed by another training sequence.

Image transmission begins when the calling unit receives the CFR signal. Another training sequence is sent, followed by the image information. The image encoding is discussed in Section 3.4. At the end of a page of image transmission, the transmitter sends one of the following signals: End Of Message (EOM), MultiPage Signal (MPS), or End Of Procedures (EOP). In the case of an EOM or an MPS signal, the transmitter returns to the beginning of stage B or C, and transmits a subsequent page of information. The training and phasing signal is always retransmitted at the start of a new page. The EOP signal indicates that the complete document has been transmitted. In the case of a manual transmitter, operator intervention may be requested following the transmission of the image page. In this case, the transmitter will send one of the following PRocedure Interrupt signals: PRI-EOM, PRI-MPS, or PRI-EOP. The exact meaning of these signals is discussed in Section 3.2. If an optional error correction mode is employed during transmission, the end of the transmitted page is signified by one of the following Partial Page Signals: PPS-EOM, PPS-MPS, PPS-EOP, PPS-NULL, PPS-PRI-EOM, PPS-PRI-MPS, or PPS-PRI-EOP. This is the T.4 error correction mode, and is discussed in Section 3.5.

After receiving one of the above end of page signals, the receiver will generally respond with either a Message ConFirmation (MCF) signal or a ReTrain Positive (RTP) signal, assuming that the page was received with an acceptable number of errors. Upon receiving an MCF signal, the transmitter sends a training/phasing sequence, followed by the next page of information. Upon receiving an RTP signal, the transmitter will return to Phase B and will issue another DCS command, followed by a training/phasing sequence, and the next page of information. If the original page of information was received with an unacceptable number of errors, the receiver will issue a Retrain Negative (RTN) signal upon receiving an end of page command from the transmitter. The transmitter will then send a DCS and training signal, and will then retransmit the previous page of information. If the receiver continually responds with RTN, the transmitter may lower the data rate of the image transmission, and advise the receiver of this via a DCS signal. The training and image transmission will then take place at the lower data rate. This is

an optional feature known as fallback. It should be noted that neither the RTP nor RTN signals are applicable to the T.4 error correction mode of transmission.

Following the reception of an MCF signal, the transmitter will send a DisCoNnect (DCN) signal. After this, both transmitter and receiver disconnect, and the call is completed.

A similar sequence of handshaking occurs when the call originator wishes to receive a facsimile. This situation is illustrated in Figure 3.3. As in the previous case the first two sequences of information are provided by the called unit, in this case the transmitter. Upon reception of the DIS, the calling receiver transmits a Digital Transmit Command (DTC) signal, in which it identifies its capabilities to the called transmitter. This command is analogous to the DIS signal provided by the transmitter at the origin of the call. At this time two optional signals may also be sent. The CallInG subscriber identification (CIG) is used by the calling receiver to identify its international telephone number to the transmitter. Any non standard capabilities of the calling receiver are identified in a Non Standard facility Command (NSC) signal. These two optional signals are analogous to the CID and NSF signals respectively. The res[illegible] the handshaking between the facsimile transmitter and facsimile receiver is identical to the [illegible]ous case.

3.2 V.21 Modulation and HDLC Coding

Most of the signalling which takes place during Phases B and D of the procedure occurs using the V.21 modulation. This is a simple Frequency Shift Keyed (FSK) modulation with mark and space frequencies of 1650 Hz, and 1850 Hz respectively. A standard data rate of 300 bits per second (bps) is used, but an optional data rate of 2400 bps is also specified. The initial signalling between facsimile units is always done at a rate of 300 bps The only non-V.21 signalling occurring during these phases is a modem training/phasing sequence which takes place during Phase B, and is used to train the receiver modem. This training sequence is sent using V.29, or V.27*ter* modulation, and will be discussed in Section 3.3.

As mentioned in the previous section, the data is arranged and transmitted in a group of one or more frames of bits. These frames are structured according to the CCITT High Level Data Link Control (HDLC) standard. The exact HDLC frame format is shown in Figure 3.4, which illustrates an example of an HDLC sequence sent by a called receiver at the beginning of Phase B of the procedure. Each frame contains the information to be transmitted, as well as an error detection capability. A unique **flag** sequence, located at the beginning and end of each frame is used as a delimiter. When more than one frame is sent sequentially, the closing flag of the first frame may be used as the opening flag of the next frame. The flag sequence is the bit pattern **01111110**. This pattern is unique and can never appear within the transmitted frame, only at the beginning or the end. Of course, this pattern could conceivably appear within the data to be transmitted. In order to ensure that it is not transmitted within the HDLC frame, a bit stuffing procedure known as zero insertion is used. With the exception of the delimiting flags, the transmitter will insert a **0** after each occurrence of five consecutive **1**'s. At the receive side, the receiver monitors the incoming bit stream for a sequence of five consecutive ones. If detected, and the next bit is a **0**, that **0** is ignored. If the five **1**'s are followed by a **1** and a **0**, a flag is recognized. If the receiver detects a pattern of seven consecutive **1**'s, it is assumed that the transmitting station has sent an abort signal.

Calling Receiver Procedure		Called Transmitter Procedure
	Phase A	
	←	1. Transmit CED
	Phase B	
3. Detect DIS	←	2. Transmit DIS, (NSF), (CID)
4. Transmit DTC, (CIG), (NSC)	→	5. Detect DTC
7. Detect DCS	←	6. Transmit DCS
8. Select Mode		
10. Training/Phasing	←	9. Transmit Phasing/Training Sequence
11. Transmit CFR	→	12. Detect CFR
	Phase C	
14. Receive Image	←	13. Transmit Image
	Phase D	
16. Receive one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS, PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS	←	15. At end of page, send one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS,PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS
17. Transmit MCF or RTP	→	18. Receive MCF or RTP. If Document Transmission Is Complete, Proceed To Phase E, Otherwise Go Back To Phase B, or C
	Phase E	
20. Receive DCN	←	19. Transmit DCN
21. Disconnect		21. Disconnect

Figure 3.3: Facsimile Procedure For Calling Receiver and Called Transmitter

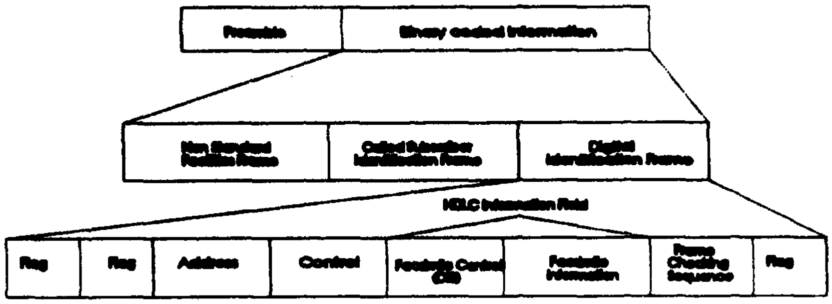

Figure 3.4: Sequence Of HDLC Frames Sent By Called Facsimile At Beginning Of Phase B

HDLC frames are generally sent in a group, with each frame in the group consisting of one of the handshaking signals discussed in the previous section. Each sequence of frames begins with a series of flags of approximately one second duration. This initial sequence of flags is referred to as the **preamble**, and is used by the receiver to acquire initial synchronization. The preamble is then followed by the individual HDLC frames. Each HDLC frame begins with another flag sequence, followed by an eight bit **address field**. This field is constant on the general switched telephone network, and is composed of a group of eight ones (**1111 1111**). The address field is always followed by the **control field** which is of the form **1100 X000**, where a value of X=0, indicates that another HDLC frame will follow the completion of the current one. A value of X=1, indicates that the current HDLC frame is the last one in the sequence.

The first byte of data that follows the address and control fields is called the **facsimile control field**. In this field the handshaking signals discussed in the previous section are sent. The patterns sent for each possible handshaking signal is illustrated in Tables 3.1 - 3.5.

In Tables 3.1 - 3.5, the X appearing as the first bit of the facsimile control field will be defined as follows:

- X is set to 1 by the station which receives a valid DIS signal;

- X is set to 0 by the station which receives a valid and appropriate response to a DIS signal;

- X will then remain unchanged until the station again enters the beginning of phase B.

As can be seen from Tables 3.1 - 3.5, many of the facsimile control fields are followed by an additional field of bits. This is the **facsimile information field**. It is used to augment the signal sent in the facsimile control field. In the case of a DIS, DTC, or DCS signal sent in the

facsimile control field, the facsimile information field which follows contains either 24, 32, or 40 bits. These bits are used to describe the capabilities of either the transmitting or receiving machine. Basic capabilities may be described using 24 bits, but extended capabilities require 32 or 40 bits. A 1 in bit 24 indicates that the 8 bits which follow are to be taken as a continuation of the facsimile information field. A 1 in bit 32 has identical meaning. The meaning of the bits composing the facsimile information field for DIS, DTC, and DCS signals is shown in Table 3.6. A 1 in any of the bit positions indicates that the machine has the designated option.

Table 3.1: Facsimile Control Field Data For Signals Sent At Beginning Of Phase B

SIGNAL	BIT PATTERN	DESCRIPTION
Signals Sent From Called Station To Calling Station At Beginning Of Phase B		
Digital Identification Signal (DIS)	0000 0001	Identify capabilities of called station. Always followed by a 24, 32, or 40 bit facsimile information field.
Called Subscriber Information (CSI)	0000 0010	Identify telephone number of called unit. Always followed by a 160 bit facsimile information field
Non Standard Facilities (NSF)	0000 0100	Identify optional capabilities of called unit. Always followed by a manufacturer dependent facsimile information field
Signals Sent From Calling Receiver To Called Transmitter At Beginning Of Phase B		
Digital Transmit Command (DTC)	1000 0001	Identify capabilities of calling receiver. Always followed by a 24, 32, or 40 bit facsimile information field
Calling Subscriber Identification (CIG)	1000 0010	Identify telephone number of calling receiver. Always followed by a 160 bit facsimile information field
Non Standard Facilities Command (NSC)	1000 0100	Response to NSF signal. Identify optional capabilities of calling receiver. Always followed by a manufacturer dependent facsimile information field.
Signals Sent From Transmitter To Receiver At Beginning Of Phase B		
Digital Command Signal (DCS)	X100 0001	Response to DIS or DTC signal. Always followed by a 24, 32, or 40 bit facsimile information field.

Transmitting Subscriber Identification (TSI)	X100 0010	Identify telephone number of transmitter. Always followed by a 160 bit facsimile information field.
Non Standard Facilities Set Up (NSS)	X100 0100	Response to NSF or NSC signal. Always followed by a manufacturer dependent facsimile information field.

Table 3.2: Facsimile Control Field Data For Signals Sent At End Of Phase B

SIGNAL	BIT PATTERN	DESCRIPTION
Signals Sent From Receiver To Transmitter At End Of Phase B		
Confirmation To Receive (CFR)	X010 0001	Confirms that pre-message procedure, including training, has been completed, and the message transfer may commence.
Failure To Train (FTT)	X010 0010	Rejects training/phasing sequence sent during phase B, and requests retraining.

Facsimile control fields which contain CSI, CIG, or TSI signals are always followed by a 160 bit facsimile information field which identifies the telephone number of the sending unit. The full international telephone number is coded as 20 digits. Each digit is coded according to the scheme shown in Table 3.7. The digits are sent in a bit reversed order, such that the least significant bit of the least significant digit is the first one transmitted. Facsimile control fields containing a NSF, NSC, or NSS signal are also followed by facsimile information fields. These are used to augment the non standard capabilities of the sending machine. The coding scheme used in these fields is not standard, and is left to the discretion of the manufacturer.

The facsimile control field is followed by a 16 bit **frame check sequence**. This is used by the receiver to detect any errors which may occur during the transmission of the HDLC frame [9]. The information contained in the 16 bit field is given by the one's complement of the modulo 2 sum of the following two values.

1) The remainder of $x^k (x^{15} + x^{14} + x^{13} + ... + x^2 + x + 1)$ divided (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$. k is the number of bits in the frame existing between, but not including, the final bit of the opening flag and the first bit of the frame check sequence. Any zeros which occur in the frame as the result of zero insertion are ignored in this calculation.

2) The remainder after multiplication by x^{16} and then division (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^{5} + 1$ of the content of the frame existing between, but not including, the final bit of the opening flag and the first bit of the frame check sequence. Any zeros which occur in the frame as the result of zero insertion are ignored in this calculation.

Table 3.3: Facsimile Control Field Data For Post Message Signals Sent From Transmitter To Receiver During Phase D

SIGNAL	BIT PATTERN	DESCRIPTION
Post Message Commands Sent From Transmitter To Receiver		
End Of Message (EOM)	X111 XXXX	Indicates the end of a complete page of transmission, and that transmitter will return to beginning of Phase B upon receipt of confirmation. EOM should not be used in the T.4 Error Correction mode.
Multipage Signal (MPS)	X111 0001	Indicates the end of a complete page of transmission, and that transmitter will return to beginning of Phase C upon receipt of confirmation. MPS should not be used in the T.4 Error Correction mode.
End Of Procedure (EOP)	X111 0100	Indicates the end of document transmission, and that transmitter will proceed to Phase E upon receipt of confirmation. EOP should not be used in the T.4 Error Correction mode.
Procedure Interrupt - End Of Message (PRI-EOM)	X111 1001	Indicates the same as an EOM, but also requests operator intervention at receiver. Once operator intervention is accomplished, transmitter will return to beginning of Phase B. PRI-EOM should not be used in the T.4 Error Correction mode.
Procedure Interrupt - Multipage Signal (PRI-MPS)	X111 1010	Indicates the same as an MPS, but also requests operator intervention at receiver. Once operator intervention is accomplished, transmitter will return to beginning of Phase B. PRI-MPS should not be used in the T.4 Error Correction mode.

Procedural Interrupt Negative (PIN)	X011 0100	Indicates that a message was not received satisfactorily, and that further transmission should not continue without operator intervention at the transmitter. Failing the operator intervention, the facsimile procedure returns to the beginning of Phase B.

Table 3.5: Facsimile Control Field Data For Line Control Signals

SIGNAL	BIT PATTERN	DESCRIPTION
Line Control Signals		
Disconnect (DCN)	X101 1111	Indicates the initiation of Phase E.
Command Repeat (CRP)	X101 1000	Indicates that previous HDLC sequence received in error and that it should be repeated in its entirety.

At the receiver, the bit stream composed of the HDLC frame data and the frame check sequence is divided by the same generator polynomial described above. As before, the final bit of the opening flag and any zeros inserted as a result of the zero insertion procedure are ignored in the calculation. The division will result in a remainder of 0001110100001111 (x^{15} through x^{0}, respectively) in the absence of any transmission errors.

An example of the bit stream contained in an HDLC sequence sent at the beginning of Phase B by a called receiver is shown in Figure 3.8. This figure illustrates the exact bit stream associated with the HDLC sequence illustrated in Figure 3.4.

Table 3.6: Facsimile Information Field For DIS, DTC, and DCS Signals

Bit Number	Meaning Following DIS or DTC Facsimile Control Field	Meaning Following DCS Facsimile Control Field
1	Group I Transmission	
2	Group I Reception	Group I Reception
3	Group I Index Of Cooperation = 176	Group I Index Of Cooperation = 176
4	Group II Transmission	
5	Group II Reception	Group II Reception
6	Reserved	
7	Reserved	
8	Reserved	
9	Group III Transmission	
10	Group III Reception	Group III Reception
11, 12	Image Transmission Capabilities	Image Reception Modulation and Data Rates
(0,0)	V.27*ter* fallback mode	2400 bits/sec V.27*ter*
(0,1)	V.27*ter*	4800 bits/sec V.27*ter*
(1,0)	V.29	9600 bits/sec V.29
(1,1)	V.29 and V.27*ter*	7200 bits/sec V.29
13	Reserved	
14	Reserved	
15	Vertical Scanning Resolution	Vertical Scanning Resolution
(0)	3.85 lines/mm	3.85 lines/mm
(1)	7.7 lines/mm	7.7 lines/mm
16	Two Dimensional Image Coding Capability	Two Dimensional Image Coding Capability

17, 18	<u>Recording Width Capabilities</u>	<u>Recording Width Capabilities</u>
(0,0)	1728 PELS along scan line length of 215 mm +/- 1%	1728 PELS along scan line length of 215 mm +/- 1%
(0,1)	1728 PELS along scan line length of 215 mm +/- 1%, and 2048 PELS along scan line length of 255 mm +- 1%, and 2432 PELS along scan line length of 303 mm +- 1%.	2432 PELS along scan line length of 303 mm +- 1%.
(1,0)	1728 PELS along scan line length of 215 mm +/- 1%, and 2048 PELS along scan line length of 255 mm +- 1%.	2048 PELS along scan line length of 255 mm +- 1%.
(1,1)	Invalid	Invalid
19,20	<u>Recording Length Capabilities</u>	<u>Recording Length Capabilities</u>
(0,0)	A4 (297 mm)	A4 (297 mm)
(0,1)	Unlimited	Unlimited
(1,0)	A4 (297 mm) and B4 (364 mm)	A4 (297 mm) and B4 (364 mm)
(1,1)	Invalid	Invalid
21, 22, 23	<u>Scan Time Capability</u>	<u>Minimum Scan Time</u>
(0,0,0)	20 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$	20 ms
(0,0,1)	40 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$	40 ms
(0,1,0)	10 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$	10 ms
(1,0,0)	5 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$	5 ms
(0,1,1)	10 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$	
(1,1,0)	20 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$	
(1,0,1)	40 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$	
(1,1,1)	0 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$	0 ms
Note: $T_{7.7}$ and $T_{3.85}$ refer to the scan line times for vertical scan modes of 7.7 lines/mm and 3.85 lines/mm respectively.		
24	Extend Field	Extend Field

25	2400 bits/sec Handshaking	2400 bits/sec Handshaking
26	Uncompressed Mode	Uncompressed Mode
27	Error Correction Mode	Error Correction Mode
28	Set To 0	Frame Size: 0 = 256 bytes 1 = 64 bytes
29	Error Limiting Mode	Error Limiting Mode
30	Reserved	Reserved
31	Unassigned	
32	Extend Field	Extend Field
33	Validity Of Bits 17 and 18	Recording Width
(0)	Bits 17 and 18 are valid.	Use recording width indicated by bits 17 and 18.
(1)	Bits 17 and 18 are invalid.	Use recording width information in bits 34 - 37.
34	Recording Width Capability 1216 PELS along scan line of length 151 mm +/- 1%	Use middle 1216 PELS of 1728 PELS
35	Recording Width Capability 864 PELS along scan line of length 107 mm +/- 1%	Use middle 864 PELS of 1728 PELS
36	Recording Width Capability 1728 PELS along scan line of length 107 mm +/- 1%	Invalid
37	Recording Width Capability 1728 PELS along scan line of length 107 mm +/- 1%	Invalid
38	Reserved	Reserved
39	Reserved	Reserved
40	Extend Field	Extend Field

Table 3.7: Digit Coding For CSI. CGI, or TSI Facsimile Information Field

Digit	Bit Pattern
+	00101011
0	00110000
1	00110001
2	00110010
3	00110011
4	00110100
5	00110101
6	00110110
7	00110111
8	00111000
9	00111001
Space	00100000

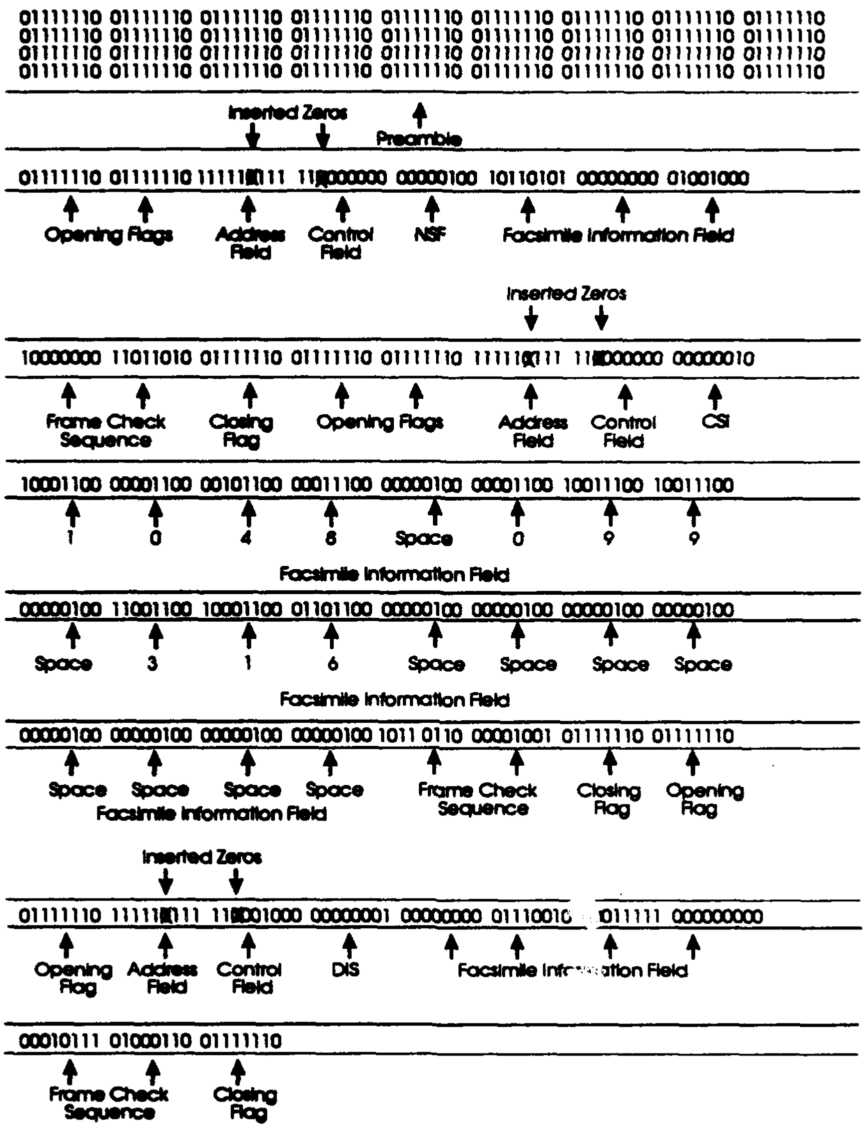

Figure 3.5: Bit Pattern For HDLC Sequence Shown In Figure 3.4

3.3 V.29 and V.27*ter* Signalling

The facsimile image in a Group III machine is encoded as a digital bit stream and sent using one of two modulation schemes: V.29, or V.27*ter*. The image encoding techniques will be discussed in Section 3.4.

V.29 modulation is an M-ary Quadrature Amplitude Modulation (QAM) scheme employing either 16, 8, or 4 levels for data rates of 4800, 7200, and 9600 bits per second (bps) respectively. The highest data rate possible for channel conditions is used. In each case, the transfer of information takes place at a baud rate of 2400 symbols per second. A carrier frequency of 1700 Hz is used. In the 9600 bps case, each transmitted symbol is composed of four bits. The first bit (Q1) determines the relative amplitude of the transmitted element. These amplitudes are measured relative to the unmodulated carrier. Bits Q2, Q3, and Q4 are encoded as a phase change, relative to the phase of the previous symbol. The amplitude and relative phase encoding for the 9600 bps case can be determined from Tables 3.8 and 3.9 respectively. The signal space diagram for the 9600 bps transmission is shown in Figure 3.6

Table 3.8: Relative Signal Amplitudes For V.29 Transmission

Absolute Phase	Q1	Relative Signal Element Amplitude
0^0, 90^0, 180^0, 270^0	0	3
	1	5
45^0, 135^0, 225^0, 315^0	0	$\sqrt{2}$
	1	$3\sqrt{2}$

For 7200 bits per second transmission, each transmitted symbol is composed of three bits. The relative phase change for each symbol is determined by using these three data bits as Q2, Q3, and Q4 in Table 3.9. The amplitudes for Q1 = 0, in Table 3.8 are used. The resulting signal has a signal space diagram as shown in Figure 3.6.

For 4800 bits per second transmission, each transmitted symbol is composed of two bits. The relative phase changes are determined by using the data bits as Q2, and Q3 in Table 3.9. Q4 is determined by the inverse of the modulo 2 addition of Q2 and Q3. The resulting signal space diagram is shown in Figure 3.6.

Table 3.9: Phase Changes For V.29 Transmission

Q2	Q3	Q4	Phase Change
0	0	1	0^0
0	0	0	45^0
0	1	0	90^0
0	1	1	135^0
1	1	1	180^0
1	1	0	225^0
1	0	0	270^0
1	0	1	315^0

In order to ensure that the transmitter and receiver both have a common zero phase reference, a synchronizing/phasing signal is used to train the V.29 demodulator. As mentioned in Section 3.2, this training sequence takes place during Phase B of the facsimile procedure. It consists of 4 phases, and is shown in Figure 3.7. The 128 alterations which follow the initial period of silence are used by the receiver to acquire initial synchronization. The first signal symbol transmitted during this set of alterations is used by the receiver to establish the absolute phase reference of 180^0 [10]. This symbol is shown as the A symbol in Figure 3.8. The phase and amplitude of the second symbol (**B**) in the series of alterations varies according to the data rate used. The position of the **B** symbol in the signal space diagram is shown in Figure 3.8, for all three data rates. The series of alterations consists of a repetition of the symbol pattern ABABAB for the duration of Segment 2. Segment 3 of the training sequence consists of the transmission of an equalizer conditioning pattern. During this phase, two symbols are used. Symbol C in Figure 3.8 is used to represent a **0**. Symbol D is used to represent a **1**. The exact pattern of **0**'s and **1**'s is generated according to the polynomial $1 + x^{-6} + x^{-7}$, and continues for 384 symbol intervals. Segment 4 of the training/phasing sequence consists of the transmission of a series of **1**'s, which are scrambled according to the self synchronizing data scrambling algorithm specified for V.29 transmissions. All V.29 compatible modems implement this scrambling/descrambling algorithm, and generally its use is transparent to the user. The scrambling algorithms consists of the division of the data sequence by the generating polynomial $1 + x^{-18} + x^{-23}$. Initial synchronization of the scrambler and descrambler circuits is ensured by loading the scrambler circuit with **0**'s during the transmission of Segments 1, 2, and 3. A more detailed description of the V.29 scrambling algorithm is available in the V.29 specifications [10].

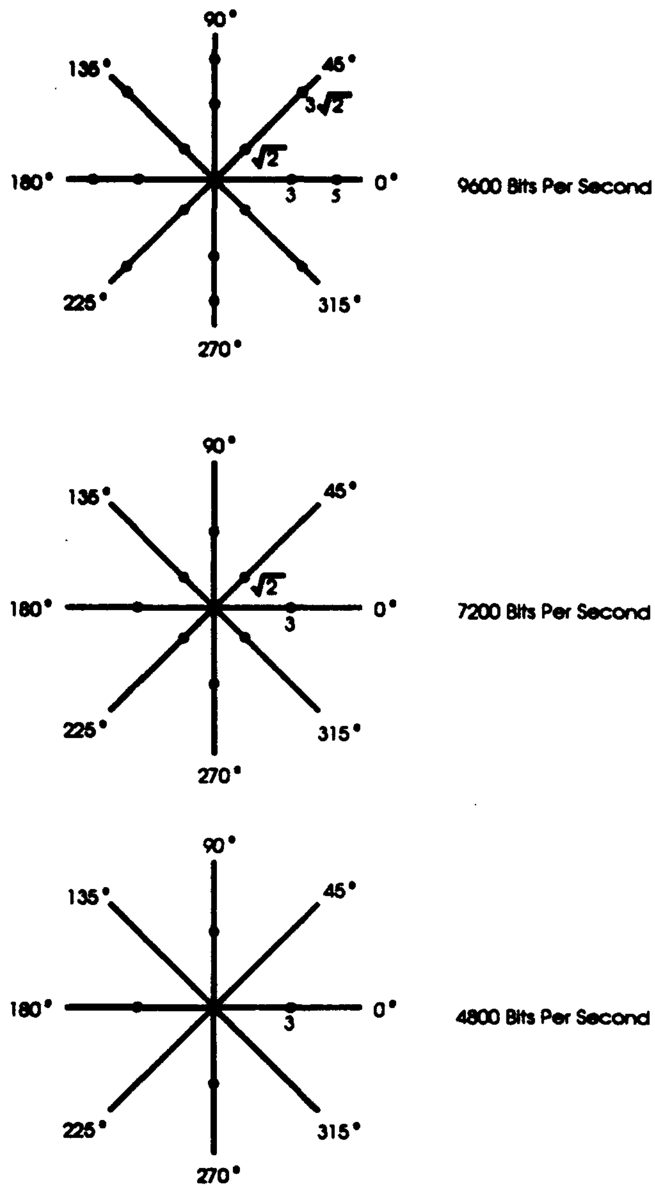

Figure 3.6: Signal Space Diagram For V.29 Modulation

Segment 1	Segment 2	Segment 3	Segment 4
Silence (48 Symbol Intervals)	Alterations (128 Symbol Intervals)	Equalizer Conditioning Pattern (384 Symbol Intervals)	Scrambled ONES (48 Symbol Intervals)

Figure 3.7: V.29 Training/Phasing Sequence

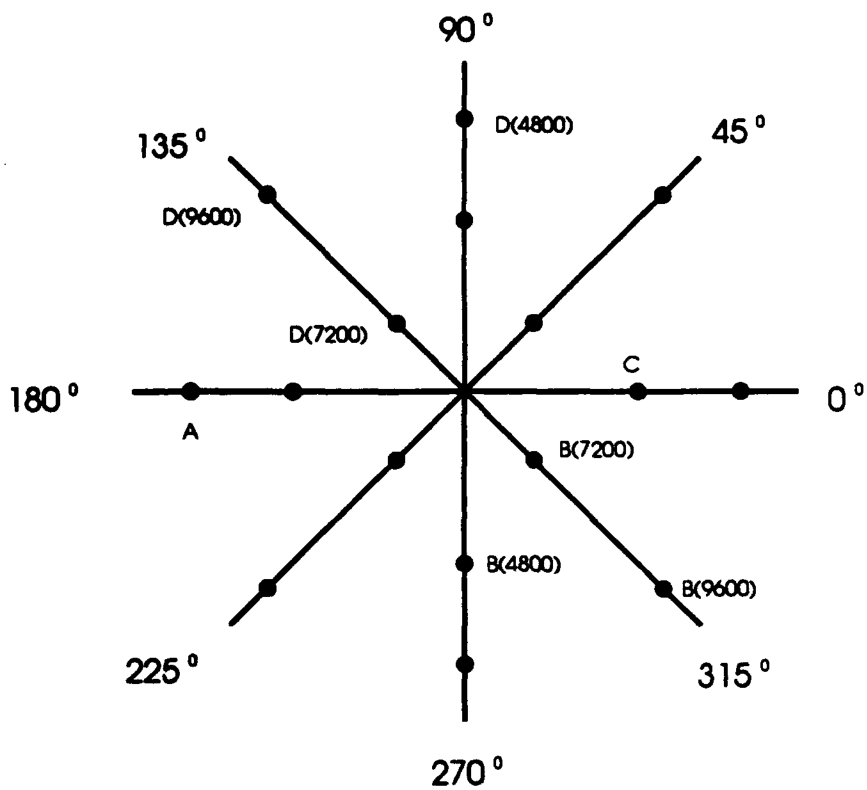

Figure 3.8: Signal Space Positions For V.29 Training Symbols (9600, 7200, and 4800 Bits Per Second)

V.27*ter* signalling is the second modulation technique employed for the transmission of image information during the facsimile procedure. V.29 modulation tends to be more common on land line links, whereas V.27*ter* is used more often on those facsimile transmission where a radio link is used at some point. V.27*ter* is an M-ary Differential Phase Shift Keyed (DPSK) modulation which employs either eight, or four levels for data rates of 4800, and 2400 bits per second respectively. As in the case of V.29 modulation, the highest data rate compatible with the channel is used. In either case the symbol rate is 2400 symbols per second.

In the case of 4800 bps transmission, each symbol is composed of three data bits. The phase changes are for each tri-bit combination are shown in Table 3.10.

Table 3.10: Phase Changes For 4800 Bits Per Second, V.27*ter* Modulation

Tri-Bit Combination	Phase Change
001	0^0
000	45^0
010	90^0
011	135^0
111	180^0
110	225^0
100	270^0
101	315^0

For 2400 bps transmission, each symbol is composed of a group of two data bits. The phase change associated with each one of these symbols is shown in Table 3.11. Signal space diagrams for V.27*ter* transmissions are shown in Figure 3.9 for data rates of 4800 and 2400 bps.

Table 3.11: Phase Changes For 2400 Bits Per Second, V.27*ter* Modulation

Data Bit Pair	Phase Change
00	0^0
01	90^0
11	180^0
10	270^0

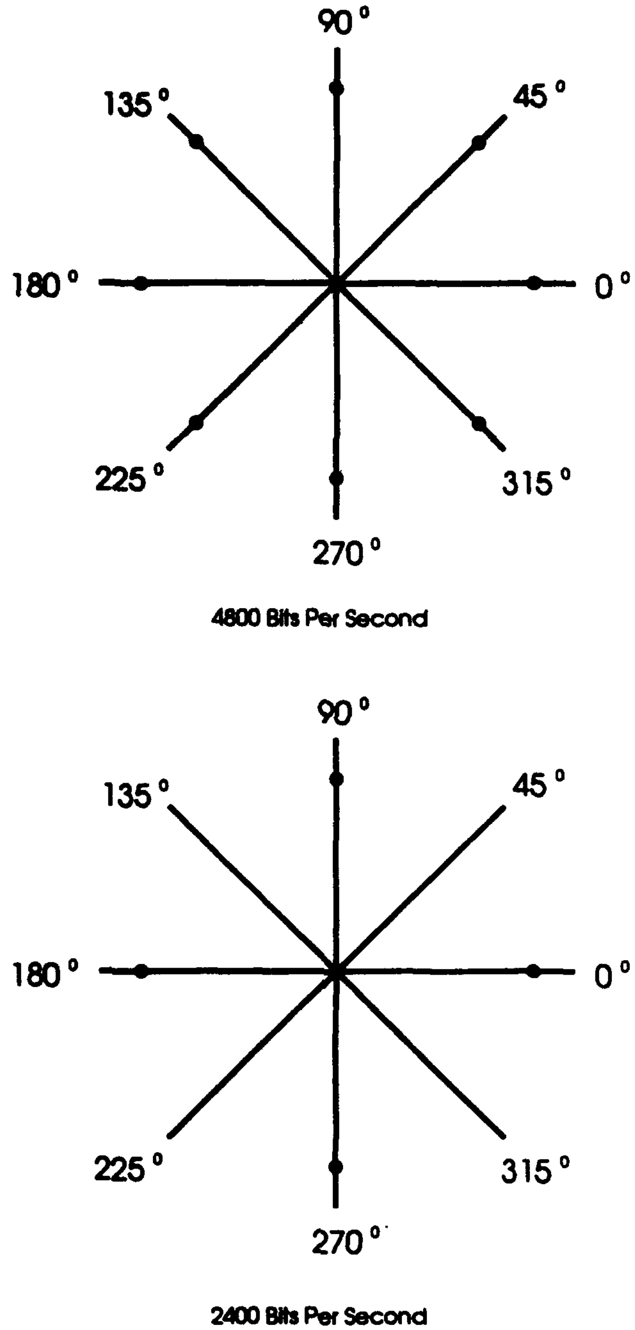

Figure 3.9: Signal Space Diagram For V.27*ter* Modulation

The training/phasing sequences used for V.27*ter* signalling consists of five phases. These are shown in Figure 3.10. There are two possible training sequences used. The longer sequence is used at the beginning of the call for initial synchronization. The shorter sequence is used during the call to maintain synchronization during the procedure; between pages of text for example. The first two segments of either sequence (the unmodulated carrier and silence intervals) may be omitted if protection against talker echo is not required. The equalizer conditioning pattern is derived from a pseudo random sequence generated by the polynomial $1 + x^{-6} + x^{-7}$. Every third bit of this pseudo random sequence is used to determine the transmitted symbol. When the bit is a **0**, the symbol corresponding to zero degrees in Table 3.10, or 3.11 is transmitted. When the pattern contains a **1**, the symbol corresponding to 180^0 in Table 3.10, or 3.11 is transmitted. The final segment of the V.27*ter* training sequence consists of a group of scrambled ones. As with the V.29 modulation, a scrambling algorithm is specified for V.27*ter* modulation. The data is scrambled by dividing the message sequence with the generating polynomial $1 + x^{-6} + x^{-7}$. A more detailed description of the scrambling algorithm used for V.27*ter* modulation is available in the V.27*ter* specifications [10].

Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Unmodulated Carrier (185 - 200 msec)	Silence (20 - 25 msec)	180° Phase Reversals (50 Symbol Intervals)	Equalizer Conditioning Pattern (1074 Symbol Intervals)	Scrambled ONES (8 Symbol Intervals)

Long Training Sequence

Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Unmodulated Carrier (185 - 200 msec)	Silence (20 - 25 msec)	180° Phase Reversals (14 Symbol Intervals)	Equalizer Conditioning Pattern (58 Symbol Intervals)	Scrambled ONES (8 Symbol Intervals)

Short Training Sequence

Figure 3.10: V.27*ter* Training/Phasing Sequence

3.4 Image Encoding

The facsimile image is digitally encoded using one of two schemes outlined in the CCITT Recommendations T.4 [8]. The encoded bit stream is then sent during Phase C of the transmission, using either V.29 or V.27*ter* modulation. All facsimile machines must be capable of encoding and decoding the image using the basic one dimensional format. As an option, a two dimensional encoding scheme is available which is somewhat more efficient that the single dimensional procedure, but less common. The scheme used in any given transmission is determined during the handshaking which occurs in Phase B of the procedure. Bit 16 of the 40 bit facsimile information field following a DIS, DTC, or DCS signal specifies the encoding capability of the machine. (See Table 3.6.) Both schemes used for image encoding are discussed below.

3.4.1 One-Dimensional Image Encoding

In the one-dimensional encoding scheme, each 215 mm horizontal scan line is represented by a total of 1728 Picture ELementS (PELS). Each data line, representing one scan line, consists of alternating white and black run codes which specify the number of consecutive white or black PELS. A Huffman encoding scheme is used in which short code words are allocated to those white and black run lengths occurring more often in practice. To ensure that the receiver maintains colour synchronization, each data line begins with a white run length code word. If the scan line begins with a black colour, a white run length of zero is sent.

The code words used are of two types: Terminating Code Words and Make-Up Code Words. Run lengths in the range of 0 to 63 PELS are encoded with their appropriate Terminating Code Word. Run lengths in the range of 64 to 1728 pels are encoded using both a Make-Up Code Word, followed by a Terminating Code Word. The Make-Up Code Word specifies the largest length which is equal to or shorter than that required. The Terminating Code Word which follows specifies the difference between the required length and the run length represented by the Make-Up Code Word. The code words used to represent Terminating Code Words are shown in Table 3.12. Make-Up Code Words are shown in Table 3.13. These tables were taken from Reference 8.

Table 3.12: Terminating Code Words

White Run Length	Code Word	Black Run Length	Code Word
0	00110101	0	0000110111
1	000111	1	010
2	0111	2	11
3	1000	3	10
4	1011	4	011
5	1100	5	0011
6	1110	6	0010

7	1111	7	00011
8	10011	8	000101
9	10100	9	000100
10	00111	10	0000100
11	01000	11	0000101
12	001000	12	0000111
13	000011	13	00000100
14	110100	14	00000111
15	110101	15	000011000
16	101010	16	0000010111
17	101011	17	0000011000
18	0100111	18	0000001000
19	0001100	19	00001100111
20	0001000	20	00001101000
21	0010111	21	00001101100
22	0000011	22	00000110111
23	0000100	23	00000101000
24	0101000	24	00000010111
25	0101011	25	00000011000
26	0010011	26	000011001010
27	0100100	27	000011001011
28	0011000	28	000011001100
29	00000010	29	000011001101
30	00000011	30	000001101000
31	00011010	31	000001101001
32	00011011	32	000001101010
33	00010010	33	000001101011
34	00010011	34	000011010010
35	00010100	35	000011010011
36	00010101	36	000011010100
37	00010110	37	000011010101
38	00010111	38	000011010110

39	00101000	39	000011010111
40	00101001	40	000001101100
41	00101010	41	000001101101
42	00101011	42	000011011010
43	00101100	43	000011011011
44	00101101	44	000001010100
45	00000100	45	000001010101
46	00000101	46	000001010110
47	00001010	47	000001010111
48	00001011	48	000001100100
49	01010010	49	000001100101
50	01010011	50	000001010010
51	01010100	51	000001010011
52	01010101	52	000000100100
53	00100100	53	000000110111
54	00100101	54	000000111000
55	01011000	55	000000100111
56	01011001	56	000000101000
57	01011010	57	000001011000
58	01011011	58	000001011001
59	01001010	59	000000101011
60	01001011	60	000000101100
61	00110010	61	000001011010
62	00110011	62	000001100110
63	00110100	63	000001100111

Table 3.13: Make Up Code Words

White Run Length	Code Word	Black Run Length	Code Word
64	11011	64	0000001111
128	10010	128	000011001000
192	010111	192	000011001001
256	0110111	256	000001011011
320	00110110	320	000000110011
384	00110111	384	000000110100
448	01100100	448	000000110101
512	01100101	512	0000001101100
576	01101111	576	0000001101101
640	01100111	640	0000001001010
704	011001100	704	0000001001011
768	011001101	768	0000001001100
832	011010010	832	0000001001101
896	011010011	896	0000001110010
960	011010100	960	0000001110011
1024	011010101	1024	0000001110100
1088	011010110	1088	0000001110101
1152	011010111	1152	0000001110110
1216	011011000	1216	0000001110111
1280	011011001	1280	0000001010010
1344	011011010	1344	0000001010011
1408	011011011	1408	0000001010100
1472	010011000	1472	0000001010101
1536	010011001	1536	0000001011010
1600	010011010	1600	0000001011011
1664	011000	1664	0000001100100
1728	010011011	1728	0000001100101
EOL	000000000001	EOL	000000000001

The End Of Line (EOL) code word in Table 3.13 signals the end of each line of data. Since this code word is unique, it allows the receiving facsimile to reacquire line synchronization in the event that a transmission error occurs. A new line is started upon reception of an EOL word. An error occurring during a data line is easily detectable, since the decoded information between any two EOL code words should add up to 1728 PELS. At the end of each page of transmission, a series of six consecutive EOLs is sent. This is the Return To Control (RTC) signal which is used to signal to the receiver that the page of information is complete, and that Phase D of the procedure will immediately follow. After sending the RTC signal, the facsimile transmitter will immediately send an HDLC encoded post message procedure signal using the V.21 modulation.

Occasionally, the time required to transmit the Terminating Code Word, Make-Up Code Word, and EOL will be less than the minimum scan time specified in bits 21, 22, and 23 of the 40 bit facsimile information field which follows the DCS signal sent by the transmitter. When this condition occurs, the transmitter will insert a sequence of zeros between the scan line data and the EOL character. This variable length string of zero fill, ensures that the time to transmit a line of data is never less than the minimum scan time specified.

As can be seen in Table 3.6, there are optional higher resolution scanning capabilities specified, in which a single horizontal scan line may be represented by more than 1728 PELS. In these cases, the additional Make Up Code Words shown in Table 3.14 are used. The same code words are used for black run and white run lengths. The actual colour is determined by the Terminating Code Word which follows. The last two code words shown in Table 3.13 are not yet used, but are included for future systems.

Table 3.14: Optional Make Up Code Words

Run Length (White Or Black)	Code Word
1792	00000001000
1856	00000001100
1920	00000001101
1984	000000010010
2048	000000010011
2112	000000010100
2176	000000010101
2240	000000010110
2304	000000010111
2368	000000011100

2432	000000011101
2496	000000011110
2560	000000011111

3.4.2 Two-Dimensional Coding Scheme

The two-dimensional coding scheme is an optional extension of the one-dimensional coding scheme described in Section 3.4.1. If used, the document is not encoded entirely using the two-dimensional scheme. In standard vertical resolution mode of 3.85 lines/mm, single dimensional encoding is used on a minimum of every second horizontal scan line. For the higher vertical resolution mode of 7.7 lines/mm, every fourth horizontal scan line is single dimensionally encoded. As in the low resolution case, this figure is a minimum value, and single dimensional encoding may be used more frequently.

The two-dimensional encoding method is based on the definitions of various types of changing picture elements, which are PELS whose colour is different than the previous element. The definitions depend on whether they are located in the line being encoded or located in the reference line, which precedes the line being encoded. Once coded, the current line becomes the reference line for the next line to be coded. The definition of the changing picture elements also depends on whether they are the first changing element on the current reference or coding line, or the next changing element on these lines. These changing PELS are defined as follows [8]:

a_0 - The reference or starting changing element on the current coding line. At the start of the coding line a_0 is set on an imaginary white changing element situated just before the first element on the line.

a_1 - The next changing element to the right of a_0 on the current coding line.

a_2 - The next changing element to the right of a_0 and of opposite colour to a_0.

b_1 - The first changing element on the reference line to the right of a_0 and of opposite colour to a_0.

b_2 - The next changing element to the right of b_1 on the reference line.

Figure 3.11 illustrates the various changing picture elements which are used in the two-dimensional encoding scheme. One of three modes is chosen for the group of picture elements being encoded. The choice of mode depends on the relationship between the picture elements shown in Figure 3.11.

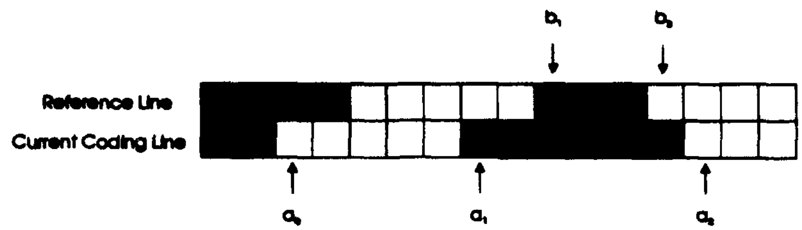

Figure 3.11: Example Of Changing Picture Elements

If b_2 lies to the left of a_1 , the Pass Mode is used. In this mode, the codeword **0001** is transmitted, and a_0 is set on the position of the element of the coding line which lies directly below b_2 in preparation for the coding of the next group of PELS to the right of the current group. If the conditions of the Pass Mode do not apply, and $|a_1 \ b_1| < 3$, the combination of a_1 and b_1 are coded using the Vertical Mode. In this mode, codewords are used to specify the relative positions a_1 and b_1. The codewords used are specified in Table 3.15. Following the encoding of the current group of PELS, the position of a_1 is used as the new starting picture element a_0 for the next group of PELS to be encoded. If the conditions of the Pass Mode, or the Vertical Mode are not met, the Horizontal Mode is used. In this mode, the colour and lengths of the group of PELS between a_0 to a_1 and a_1 to a_2 are encoded using the single dimensional encoding scheme of Table 3.12. These code words are sent following the sequence **001**. These code words are represented by M(a_0 a_1) and M(a_1 a_2) in Table 3.15. Following the encoding of the current group of PELS, the position of a_2 is used as the new starting position a_0. An example of the three modes is given in Figure 3.12.

As in the case of one-dimensional encoding, each scan line is terminated with an EOL code. In the case of two-dimensional coding however, each EOL sequence is followed by a tag bit which is used to designate the image coding technique which will be used on the next line. A tag bit of 1 indicates that the next line shall be encoded single dimensionally. A tag bit of **0** indicates that the next line will be encoded using the two-dimensional scheme. As with the one-dimensional coding, fill may be required before the EOL code word to maintain time synchronization.

Table 3.15: Two-Dimensional Coding Table

Mode	Elements To Be Coded		Code Word	Position Of New a_0 Following Coding
Pass	b_1 , b_2		0001	Element Below b_2
Vertical	a_1 just under b_1	$\lvert a_1 b_1 \rvert = 0$	1	a_1
	a_1 to the right of b_1	$\lvert a_1 b_1 \rvert = 1$	011	
		$\lvert a_1 b_1 \rvert = 2$	000011	
		$\lvert a_1 b_1 \rvert = 3$	0000011	
	a_1 to the left of b_1	$\lvert a_1 b_1 \rvert = 1$	010	
		$\lvert a_1 b_1 \rvert = 2$	000010	
		$\lvert a_1 b_1 \rvert = 3$	0000010	
Horizontal	$a_0 a_1$, $a_1 a_2$		001 + $M(a_0 a_1)$ + $M(a_1 a_2)$	a_2

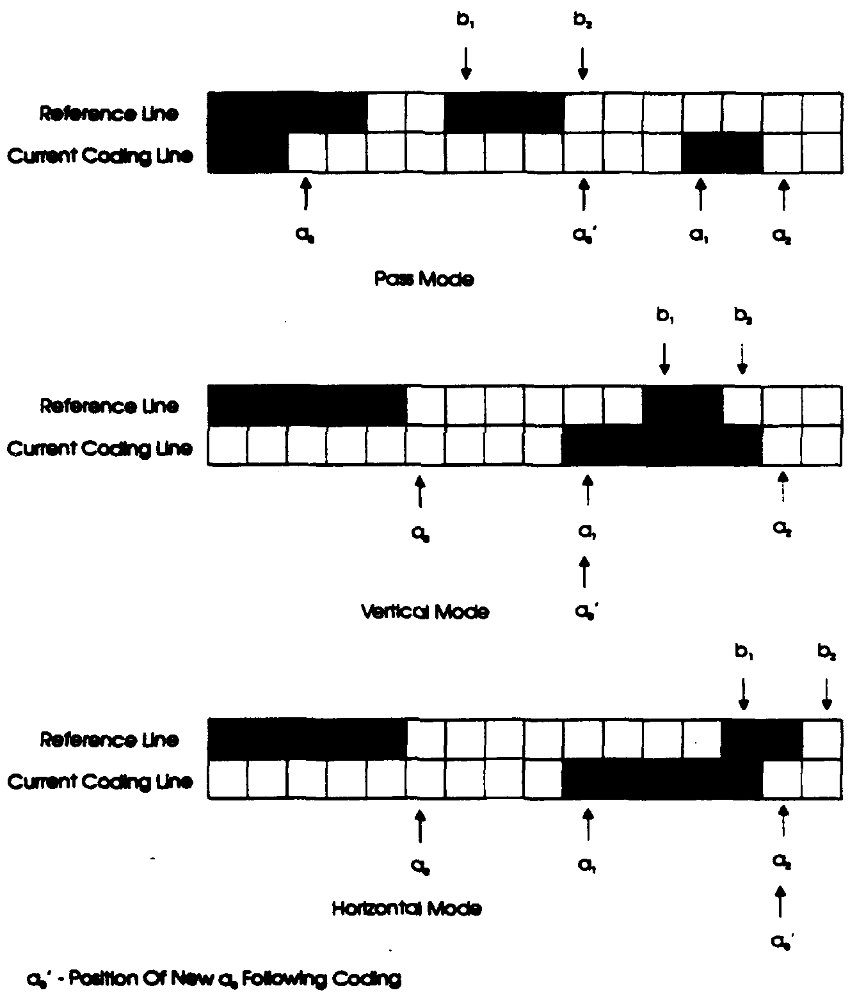

Figure 3.12: Examples Of Two-Dimensional Coding Modes

3.5 T.4 Optional Error Correction Mode

As mentioned in Section 3.1, an optional error correction mode exists for the transmission of the facsimile image information. The T.4 Error Correction Mode of transmission involves the use of HDLC frames similar to those discussed in Section 3.2. The image information is still encoded using one of the schemes outlined in Section 3.4, but the resulting sequence of bits is packed into HDLC frames. These frames are then sent using the V.29, or V.27*ter* modulation.

The structure of an HDLC frame used in T.4 Error Correction Mode is identical to that shown in Figure 3.4. The flag, address, and control sequences are identical to those used in Section 3.2. Frame checking sequences are constructed in a manner identical to that described in Section 3.2. As in the HDLC frames discussed earlier, zero insertion may be used within the frame data to prevent the occurrence of a flag sequence within the frame.

Two types of HDLC frames are used in the error correction mode. If the facsimile control field of the HDLC frame is set to **0110 0001**, the HDLC frame is designated as a Return to Control for Partial page (RCP) frame. There is no facsimile information field following the facsimile control field in an RCP frame. These frames are used to signal the end of a page of image information. Three consecutive RCP frames are used to signal to the receiver that the page of information is complete, and that Phase D of the procedure will follow immediately. Signalling which follows the transmission of these three frames will occur using V.21 modulation.

If the facsimile control field of the HDLC frame is set to **0110 0000**, the HDLC frame is designated as a facsimile coded data frame. These frames contain the image information in the facsimile information field which follows the facsimile control field. The stream of bits which compose the scanned data lines is broken up into frames of either 64 or 256 bytes. This choice is done at the discretion of the transmitting system and is indicated using bit 28 of the facsimile information field following the DCS signal in Phase B. As shown in Table 3.6, a **0** indicates that a frame size of 256 bytes will be used. A **1** indicates a frame size of 64 bytes. The facsimile information field contained in a facsimile coded data frame will contain the 64 or 256 bytes of data, preceded by a single byte indicating the frame number. Since the maximum value of the frame byte is 256, each page of information must be broken up into 256 frames of data bits. Zero fill may be added to the image information as required to align the frame boundaries.

Error correction in the T.4 Optional Error Correction Mode is achieved through the use of a half duplex Automatic Repeat reQuest (ARQ) technique. Detection of errors occurs at the end of each facsimile coded data frame. By analyzing the frame check sequence, the receiver may determine those image frames which were received in error from the first byte of the facsimile information field. If this byte is itself corrupted, the receiver will assume that the required image frames are missing. At the end of a complete page of transmission, the receiver will issue a command to the transmitter requesting a retransmission of those frames received in error, or not at all.

The use of the T.4 Optional Error Correction Mode requires additional handshaking signals sent using V.21 modulation during Phases B and D of the facsimile procedure. As mentioned in Section 3.2, EOM, MPS, EOP, PRI-EOM, PRI-MPS, and PRI-EOP signals are not used in the error correction mode. The end of a complete or partial page of transmission in this mode is indicated by a Partial Page Signal (PPS). Upon receiving a PPS signal, the receiver will respond with either an MCF signal, if no errors were detected, or a Partial Page Request (PPR) signal. This latter signal indicates that certain frames in the previous page were received in error.

The facsimile information field which follows the PPR signal in the HDLC frame contains 256 bits. Each bit corresponds to one of the 256 image frames received during the transmission of the previous page. If the frame was received in error, or not at all, the corresponding bit in this facsimile information field will be set to 1. The transmitter will then retransmit only those frames which were received in error. If errors again occur, the receiver again responds with a PPR signal. Upon receiving four consecutive PPR signals, the transmitter will issue a Continue To Correct (CTC) Signal, indicating that it will continue to retransmit the data in question.

The facsimile information field contained in a CTC HDLC frame consists of two bytes, which are identical to bits 1-16 of the DCS facsimile information field. (See Table 3.6.) In bits 11 and 12 of this frame, the transmitting facsimile may direct the receiver to fall back to a lower data rate for the reception of the image information. When the receiver has accepted the changes indicated in the CTC signal, it responds with Response for Continue To Correct signal (CTR).

The transmitter, upon receiving a series of PPR signals, may also decide to terminate the retransmission of error frames. In this case, it will issue an End Of Retransmission (EOR) signal. At this point, the receiver responds with a Response for End of Retransmission (ERR) signal, and prepares for the reception of the next block of information.

These handshaking signals, and others used in the T.4 Optional Error Correction Mode, are shown in Table 3.16, along with the appropriate facsimile control field data for each one. X is defined as in Section 3.2.

Table 3.16: Facsimile Control Field Data For Signals Used In T.4 Error Correction Mode

SIGNAL	BIT PATTERN	DESCRIPTION
Commands Sent From Transmitter To Receiver		
Partial Page Signal (PPS)	X111 1101	Indicates the end of a complete or partial page of facsimile information. Also indicates a return to the beginning of Phase B or C upon receipt of a valid MCF signal.
Continue To Correct (CTC)	X100 1000	Sent by the transmitter in response to the fourth consecutive received PPR signal. Followed by a 16 bit facsimile information field which may direct receiver to lower data rate.
End Of Retransmission (EOR)	X111 0011	Sent by the transmitter if it decides to terminate the retransmission of error frames. The transmitter will send the next block of information upon receipt of a ERR signal.
Receive Ready (RR)	X111 0110	Used To Request Status Of Receiver.
Commands Sent From Receiver To Transmitter		
Partial Page Request (PPR)	X011 1101	Sent by receiver to indicate that previous message was not received satisfactorily. Followed by a 256 bit facsimile information field which indicates the facsimile fields received in error.
Response For Continue To Correct (CTR)	X010 0011	Acknowledgement for CTC signal.
Response For End Of Retransmission (ERR)	X011 1000	Acknowledgement for EOR signal.
Receiver Not Ready (RNR)	X011 0111	Sent to the transmitter to indicate that the receiver is not ready to receive more data.

4.0 CONCLUSIONS

This technical note has compiled the necessary CCITT standards which apply to facsimile transmission. The emphasis has been on those standards related to Group III facsimile machines. The CCITT Group III recommendations are used in over 98 percent of the facsimile machines employed worldwide. Group I and II machines are now obsolete, and Group IV machines are not yet common.

Facsimile has gained a wide acceptance by the military as a mode of tactical communications. The main difference between civilian and military facsimile applications is that in the latter case, the users are generally mobile. At some point between the transmitting and receiving facsimile, the signal is carried on a wireless radio link. This would indicate that V.27*ter* modulation is used more commonly in military facsimile applications that in the civilian case, where the transmission is generally done over a wire link and V.29 modulation is more common. Both modulations were discussed in this note.

Future issues which will be examined include the effects of low SNR on the integrity of the received image, and the feasibility of reconstructing a partial page from a received signal in which the V.29 or V.27*ter* training sequence is missing, or corrupted.

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

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3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

FACSIMILE TRANSMISSION STANDARDS (U)

4. AUTHORS (Last name, first name, middle initial)

MUDRY, ANDREW AND POULIN, BRAD

5. DATE OF PUBLICATION (month and year of publication of document)

OCTOBER 1993

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

47

6b. NO. OF REFS (total cited in document)

10

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

DREO TECHNICAL NOTE

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

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9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

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9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

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(U) This technical note examines the requirements for facsimile transmission. An overview of the various facsimile standards are given, followed by a detailed description of the most commonly used standard; CCITT Group III. The Group III specifications are a composite of various CCITT modulation and encoding standards. These consist of V.21, V.27ter, and V.29 modulations, as well as T.4 image encoding standards, and T.30 signalling specifications. Each of these standards is described in the context of facsimile transmissions. A complete description of the handshaking which occurs between the facsimile transmitter and receiver is given.

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